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Interaction of N-vortex structures in a continuum, including atmosphere, hydrosphere and plasma

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Abstract

The results of analysis and numerical simulation of evolution and interaction of the N-vortex structures of various configuration and different vorticities in the continuum including atmosphere, hydrosphere and plasma are presented. It is found that in dependence on initial conditions the regimes of weak interaction with quasi-stationary evolution and active interaction with the "phase intermixing", when the evolution can lead to formation of complex forms of vorticity regions, are realized in the N-vortex systems. For the 2-vortex interaction the generalized critical parameter determining qualitative character of interaction of vortices is introduced. It is shown that for given initial conditions its value divides modes of active interaction and quasi-stationary evolution. The results of simulation of evolution and interaction of the two-dimensional and three-dimensional vortex structures, including such phenomena as dynamics of the atmospheric synoptic vortices of cyclonic types and tornado, hydrodynamic 4-vortex interaction and also interaction in the systems of a type of "hydrodynamic vortex – dust particles" are presented. The applications of undertaken approach to the problems of such plasma systems as streams of charged particles in a uniform magnetic field **B** and plasma clouds in the ionosphere are considered. It is shown that the results obtained have obvious applications in studies of the dynamics of the vortex structures dynamics in atmosphere, hydrosphere and plasma.

Keywords: Vortices; Interaction; Fluids; Atmosphere; Hydrosphere; Plasma

1. Introduction. Basic equations

In this paper we study numerically the interaction of the vortex structures (so-called FAVRs, see Zabusky et al., 1979) in the continuum, and, specifically, in fluids (such as atmosphere and hydrosphere) and plasmas in two-dimensional (2D) approximation, when the Euler-type equations are applicable. The Euler equation for the inviscid incompressible fluid $\frac{d\boldsymbol{u}}{dt} = \boldsymbol{F} - \frac{1}{\rho}\mathrm{grad}\, p$ in the 2D case takes form of the following set:

$$\begin{aligned} &\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = F_x - \frac{1}{\rho}\frac{\partial p}{\partial x}, \\ &\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = F_y - \frac{1}{\rho}\frac{\partial p}{\partial y}. \end{aligned} \tag{1}$$

Add here the equation of continuity:

$$\frac{d\rho}{dt} + \rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x}\right) = 0$$

where for ideal incompressible fluid $d\rho/dt = 0$ and, hence,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x} = 0. \tag{2}$$

Introduce further the flow function

$$\psi = \int |\boldsymbol{u}| \sin \alpha ds$$

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